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THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

MELODY AND THE ORIGIN OF THE MUSICAL SCALE[1]

IN the vice-presidential addresses of the American Association great latitude in the choice of subjects is allowed and taken, but there is, I believe, no precedent for choosing the review of a book, printed fifty-five years before. Helmholtz's Tonenempfindungen, produced by a masterful knowledge of physiology, physics and mathematics, and a scholar's knowledge of the literature of music, has warded off all essential criticism by its remarkable breadth, completeness and wealth of detail. Since it was first published it has been added to by the author from time to time in successive editions, and greatly bulwarked by the scholarly notes and appendices of its translator, Dr. Alexander J. Ellis. The original text remains unchanged and unchallenged on physical grounds. In taking exception at this late day to the fundamental thesis of Part III., I derive the necessary courage from the fact that should such exception be sustained, it will serve to restore to its full application that greater and more original contribution of Helmholtz which he included in Part II. Having given a physical and physiological explanation of the harmony and discord of simultaneous sounds, and therefore an explanation of the musical scale as used in modern com-

[1] Address of the vice-president and chairman of Section B—Physics—American Association for the Advancement of Science, Chicago, 1907–8.

position, Helmholtz was met by an apparent anachronism. The musical scale, identical with the modern musical scale in all essentials, antedated by its use in single part melody the invention of chordal composition, or, as Helmholtz expressed it, preceded all experience of musical harmony. In seeking an explanation of this early invention of the musical scale Helmholtz abandoned his most notable contribution, and relegated his explanation of harmony and discord to the minor service of explaining a fortunate, though, of course, an important use of an already invented system of musical notes. The explanation of the original invention of the musical scale and its use in single-part music through the classical and the early Christian eras, he sought for in purely esthetic considerations—in exactly those devices from which he had just succeeded in rescuing the explanation of harmony and discord.

The human ear consists of three parts—in the nomenclature of anatomy—of the outer, middle and inner ear. The outer and inner ears are connected by a series of three small bones traversing the middle ear and transmitting the vibrations of sound. The inner ear is a peculiarly shaped cavity in one of the hard bones of the skull. That part of the cavity with which we are here concerned is a long spiral passage called from its resemblance to the interior of a snail shell, the cochlea. The cavity has two windows which are closed by membranes. It is to the uppermost of these membranes that the train of three small bones reaching from the drum of the outer ear is attached at its inner end. It is to this upper membrane, therefore, that the vibration is communicated, and through it the vibration reaches the fluid which fills the inner cavity. As the membrane covering the upper window vibrates, the membrane covering the lower window yielding also vibrates, and the motion of the fluid is in the nature of a slight displacement from one to the other window, to and fro. From between these windows a diaphragm, dividing the passageway, extends almost the whole length of the cochlea. This diaphragm is composed in part of a great number of very fine fibers stretched side by side, transverse to the cochlea, and called after their discoverer, fibers of Corti. On this diaphragm terminate the component fibers of the auditory nerve. When the liquid vibrates the fibers vibrate in unison, the nerve terminals are stimulated, and thus the sensation of sound is produced. These fibers of Corti are of different lengths and presumably are stretched with different tensions. They therefore have different natural rates of vibration and a sympathetic resonance for different notes. The whole has been called a harp of several thousand strings.

Were these fibers of Corti very free in their vibration, each would respond to and would respond strongly only to that particular note with whose frequency it is in unison. Because of the fact that they are in a liquid, and possibly also because of the manner of their terminal connections, they are considerably damped. Because of this their response is both less in amount and less selective in character. In fact, under these conditions not one, but many fibers vibrate in response to a single pure note. A considerable length or area of the diaphragm is excited. So long as the exciting sound remains pure in quality, constant in pitch and constant in intensity, the area of the diaphragm affected and the amplitude of its vibration remain unchanged. If, however, two notes are sounded of nearly the same pitch, the areas of the diaphragm affected by the two notes overlap. In the overlapping region the vibration is violent when the two notes are in the same phase, weak when they are

in opposite phase. The result is the familiar phenomenon of beats. Such beats when slow are not disagreeable and not without musical value. If the difference between the two notes is increased the beats become more rapid and more disagreeable. To this violent disturbance, to the starting and stopping of the vibration of the fibers of Corti, Helmholtz ascribed the sense of roughness which we call discord. As the notes are more widely separated in pitch the overlapping of the affected areas diminishes. Between pure notes the sense of discord disappears with sufficient separation in pitch. When the two vibrating areas exactly match because the two notes are of exactly the same pitch, and when the two areas do not in the least overlap because of a sufficiently wide separation in pitch, the result, according to Helmholtz, is harmony. Partial overlapping of the affected areas produces beats, and the roughness of beats is discord. Such, reduced to its fewest elements, is Helmholtz's explanation of the harmony and discord of tones which are pure notes.

But no musical tone is a pure note. A musical tone always consists of a combination of so-called partial tones which bear to each other a more or less simple relationship. Of these partial tones, one is called the fundamental—so called because it is the loudest or lowest or, better still, because it is that to which the other partial tones bear the simplest relation. A musical tone, therefore, affects not one, but, through its fundamental and upper partial tones, several areas of the diaphragm in the cochlea. Two musical tones, each with its fundamental and upper partials, therefore affect areas of the diaphragm which overlap each other in a more or less complicated manner, depending on the relative frequencies of the fundamental tones and the relationships of their upper partials. The exact matching of the areas affected by these two systems of partial tones, or the entire separation of the affected areas, gives harmony. The overlapping of these affected areas, if great, produces discord, or if slight in amount, modifications and color of harmony.

In the great majority of musical tones the upper partials bear simpler relationships to the fundamentals, being integral multiples in vibration frequency. Helmholtz showed that if of two such tones one continued to sound unchanged in pitch, and the other, starting in unison, was gradually raised in pitch, the resulting discord would pass through maxima and minima, and that the minima would locate the notes of the pentatonic scale. The intermediate notes of the complete modern musical scale are determined by a repetition of this process, starting from the notes thus determined.

If to this is added a similar consideration of the mutual interference of the combinational tones which are themselves due to the interaction of the partial tones, we have the whole, though, of course, in the briefest outline, of Helmholtz's theory of the harmony and discord of simultaneously sounding musical tones.

Having thus in parts I. and II. developed a theory for the harmony and discord of simultaneous sounds, and having developed a theory which explains the modern use of the musical scale in chords and harmonic music, Helmholtz pointed out in part III. that the musical scale in its present form existed before the invention of harmonic music and before the use of chords. Music may be divided into three principal periods:

1. "Homophonic or unison music of the ancients," including the music of the Christian era up to the eleventh century, "to which also belongs the existing music of Oriental and Asiatic nations."

2. "Polyphonic music of the middle

ages, with several parts, but without regard to any independent musical significance of the harmonies, extending from the tenth to the seventeenth century."

3. "Harmonic or modern music characterized by the independent significance attributed to the harmonies as such."

Polyphonic music was the first to call for the production of simultaneous sounds and therefore for the hearing or the experience of musical harmony. Homophonic music, that which alone existed up to the tenth or eleventh century, consisted in the progression of single-part melody. Struck by this fact, Helmholtz recognized the necessity of seeking another explanation for the invention and the use of a scale of fixed notes in the music of this period. To borrow his own words, "scales existed long before there was any knowledge or experience of harmony." Again, elsewhere he says in emphasizing the point: "The individual parts of melody reach the ear in succession. We can not perceive them all at once; we can not observe backwards and forwards at pleasure." Between sounds produced and heard in discrete succession, there can be neither harmony nor discord, there can not be beats, or roughness or interruption of continuous vibrations. Regarding the sounds of a melody as not merely written in strict and non-overlapping succession, but also as produced and heard in discrete succession, Helmholtz sought another basis for the choice of the notes to constitute a scale for homophonic music. His explanation of this invention can be best presented by a few quotations:

Melody has to express a motion, in such a manner that the hearer may easily, clearly and certainly appreciate the character of that motion by immediate perception. This is only possible when the steps of this motion, their rapidity and their amount, are also exactly measurable by immediate sensible perception. Melodic motion is change of pitch in time. To measure it perfectly, the length of time elapsed, and the distance between the pitches, must be measurable. This is possible for immediate audition only on condition that the alterations in both time and pitch should proceed by regular and determinate degrees.

Again Helmholtz says:

For a clear and sure measurement of the change of pitch, no means was left but progression by determinate degrees. This series of degrees is laid down in the musical scale. When the wind howls and its pitch rises or falls in insensible gradations without any break, we have nothing to measure the variations of pitch, nothing by which we can compare the later with the earlier sounds, and comprehend the extent of the change. The whole phenomenon produces a confused, unpleasant impression. The musical scale is as it were the divided rod, by which we measure progression in pitch, as rhythm measures progression in time. Hence the theoreticians of ancient as well as modern times.

Later he says:

Let us begin with the octave, in which the relationship to the fundamental tone is most remarkable. Let any melody be executed on any instrument which has a good musical quality of tone, such as a human voice; the hearer must have heard not only the primes of the compound tones, but also their upper octaves, and, less strongly, the remaining upper partials. When, then, a higher voice afterwards executes the same melody an octave higher, we hear again a part of what we heard before, namely, the evenly numbered partial tones of the former compound tones, and at the same time we hear nothing that we had not previously heard.

What is true of the octave is true in a less degree for the twelfth. If a melody is repeated in the twelfth we again hear only what we had already heard, but the repeated part of what we heard is much weaker, because only the third, sixth, ninth, etc., partial tone is repeated, whereas for repetition in the octave, instead of the third partial, the much stronger eighth and tenth occur, etc.

For the repetition in the fifth, only a part of the new sound is identical with a part of what had been heard, but it is, nevertheless, the most perfect repetition which can be executed at a smaller interval than an octave.

Without carrying these quotations farther, they will suffice to illustrate the basis which Helmholtz would ascribe to

homophonic music and early melodic composition. On this explanation the basis of melody is purely that of rhythm and rhythm based on a scale of intervals. The scale of intervals in turn is based on a recognition conscious or subconscious of the compound character of musical tones and of the existence in tones of different pitch of partials of the same pitch. This calls for a degree of musical insight and discrimination which it is difficult to credit to a primitive art. It is in reality the skill of the highly trained musician, of a musician trained by long experience with sounds which are rich and accurate in quality. This power of analysis goes with supreme skill rather than with the early gropings of an art.

After having developed a theory of harmony and discord based on elaborate experimental and mathematical investigations, which was remarkable in bringing together three such diverse fields as physics, physiology and esthetics, he relegated it to the minor application of explaining the use in modern music of an already existing and highly developed musical scale, and sought an explanation of the earlier use of the scale in melody and its original invention in a principle which is very far from possessing either the beauty or the convincing quality of his earlier hypothesis. He was forced to this by the priority of melodic or homophonic composition. He saw in melody only a succession of notes, no two existing at the same time, and therefore incapable of producing harmony or discord in a manner such as he had been considering.

It is true that melody is written as a pure succession of discrete notes, one beginning only when the other has ceased. It is true also that melody is so sung and so produced on a homophonic instrument such as the voice, flute, reeds or on stringed instruments. This is peculiarly true of the voice, and it is with the voice that one naturally associates the earliest invention of the scale. But while it is true that the earliest song must have consisted of tones produced only in succession, it is not necessarily true that such sounds were heard as isolated notes. A sound produced in a space which is in any way confined continues until it is diminished by transmission through openings, or is absorbed by the retaining walls or contained material to such a point that it is past the threshold of audibility, and this prolongation of audibility of sound is under many conditions a factor of no inconsiderable importance. In many rooms of ordinary construction the prolongation of audibility amounts to two or three seconds and it is not exceedingly rare that a sound of moderate initial intensity should continue audible for eight, nine, or even ten seconds after the source has ceased. As a result of this, single-part music produced as successive separate sounds is nevertheless heard as overlapping, and at times as greatly overlapping tones. Each note may well be audible with appreciable intensity not merely through the next note, but through several succeeding notes. Under such conditions we have every opportunity even with single-part music for the production of all the phenomena of harmony and discord which have been discussed by Helmholtz in explanation of the chordal use of the musical scale. In any ordinarily bare and uncarpeted room, one may sing in succession a series of notes and then hear for some time afterward their full chordal effect.

All the arguments that Helmholtz advanced in support of his hypothesis that the musical scale was devised solely from considerations of rhythm and founded on a repetition of faint upper partials, hold with equal force in the explanation here proposed. The identity of partial tones in

compound tones with different fundamentals is one of the conditions of harmony, and the scale devised by considerations of the mutual harmony of the notes sounded simultaneously would, in every respect, be the same as that of a scale based on repeated upper partials. In the one case the identity of upper partials is an act of memory; in the other it is determined by the harmony of sustained tones. All the arguments by Helmholtz based on historical considerations and on racial and national differences are equally applicable to the hypothesis of sustained tones. In fact, they take on an additional significance, for we may now view all these differences not merely in the light of differences in racial development and temperament, but in the light of physical environment. Housed or unhoused, dwelling in reed huts or in tents, in houses of wood or of stone, in houses and temples high vaulted or low roofed, of heavy furnishing or light, in these conditions we may look for the factors which determine the development of a musical scale in any race, which determine the rapidity of the growth of the scale, its richness and its considerable use in single-part melody.

The duration of audibility of a sound depends on its initial intensity and on its pitch, to a small degree on the shape of the confined space, and to a very large degree on the volume of the space and on the material of which the walls are composed. The duration of audibility is only a logarithmic function of the initial intensity, and as the latter is practically always a large multiple of the minimum audible intensity, this feature of the problem may be neglected when considering it broadly. For this discussion we may also leave out of consideration the effect of shape as being both minor and too intricately variable. The pitch here considered will be the middle of the musical scale; for the extremes of the scale the figures would be very different. The problem then may be reduced to two factors, volume and material. It is easy to dispose of the problem reduced to these two elements.

The duration of audibility of a sound is directly proportional to the volume of a room and inversely proportional to the total absorbing power of the walls and the contained material. The volume of the room, the shape remaining the same, is proportional to the tube, while the area of the walls is proportional to the square of the linear dimensions. The duration of audibility, proportional to the ratio of these two, is proportional itself to the first power of the linear dimension. Other things being equal, the duration of audiblity, the overlapping of successive sounds, and therefore the experience of harmony in single-part music, are proportional to the linear dimensions of the room, be it dwelling-house or temple.

Turning to the question of material, the following figures are suggestive: Any opening into the outside space, provided that outside space is itself unconfined, may be regarded as being totally absorbing. The absorbing power of one-half-inch hard pinewood sheathing is 6.1 per cent., of plaster on wood lath 3.4 per cent., of single-thickness glass 2.7 per cent., of brick in Portland cement 2.5 per cent., of the same brick painted with oil paint 1.4 per cent. Of the others wood sheathing is nearly double any of the rest. On the other hand, a man in the ordinary clothing of to-day is equal in his absorbing power to nearly 48 per cent. of that of a square meter of unobstructed opening, a woman is 54 per cent., and a square meter of audience at ordinary seating distance is nearly 96 per cent. Of significance also in this connection is the fact that Oriental rugs have an absorbing power of nearly 29 per cent. and house plants of 11 per cent.

Of course, the direct application of these figures in any accurate calculation of the conditions of life among different races or at different periods of time is impossible, but they indicate in no uncertain manner the great differences acoustically in the environment of Asiatic races, of aboriginal races in central and southern Africa, of the Mediterranean countries, of northern Europe at different periods of time. We have explained for us by these figures why the musical scale has but slowly developed in the greater part of Asia and of Africa. Almost no traveler has reported a musical scale, even of the most primitive sort, among any of the previously unvisited tribes of Africa. This fact could not be ascribed to racial inaptitude. If melody was, as Helmholtz suggested, but rhythm in time and in pitch, the musical scale should have been developed in Africa if anywhere. These races were given to the most rhythmical dancing and the rhythmical beating of drums and tom-toms. Rhythm in time they certainly had. Moreover, failure to develop a musical scale could not be ascribed to racial inaptitude to feeling for pitch. Transported to America and brought in contact with the musical scale, the negro became immediately the most musical part of our population. The absence of a highly developed scale in Africa must then be ascribed to environment.

Turning to Europe, we find the musical scale most rapidly developing among the stone-dwelling people along the shores of the Mediterranean. The development of the scale and its increased use kept pace with the increased size of the dwellings and temples. It showed above all in their religious worship as their temples and churches reached cathedral size. The reverberation which accompanied the lofty and magnificent architecture increased until even the spoken service became intoned in the Gregorian chant. It is not going beyond the bounds of reason to say that in those churches in Europe which are housed in magnificent cathedrals the Catholic, the Lutheran and Protestant Episcopal, the form of worship is in part determined by their acoustical conditions.

This presents a tempting opportunity to enlarge on the fact that the alleged earliest evidence of a musical scale, a supposed flute, belonged to the cave-dwellers of Europe. This and the impulse to sing in an empty room, and the ease with which even the unmusical can keep the key in simple airs under such conditions, are significant facts, but gain nothing by amplification. The same may be said of the fact that since music has been written for more crowded auditoriums and with harmonic accompaniment the air has become of less harmonious sequence. These and many other instances of the effect of reverberation come to mind.

In conclusion, it may be not out of place to repeat the thesis that we would not merely with Helmholtz regard melody as rhythm in time and rhythm in pitch, but also as harmony in sustained tones, and see in the history of music, certainly in its early beginnings, but possibly also in its subsequent development, not only genius and invention, but also the effect of physical environment.

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THE RELATION OF INSTINCT TO INTELLIGENCE IN BIRDS

In the following observations an attempt is made to analyze the behavior of the wild bird in order to ascertain first, how their instincts are modified by their ability to learn, and secondly the degree of intelligence which they ordinarily attain. It may be taken as an axiom that if the bird be intelligent, it must use its intelligence in meeting the emergencies of daily life